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ABSTRACT

This paper takes the position that theories about individual differences in childhood and theories about cognitive development both would be enhanced if the two lines of research were integrated. The heuristic value of this position is illustrated in the context of analogical reasoning tasks. A general model of analogy solution and potential sources of variability in performance are outlined. Specifically, for both geometric and verbal analogy solution, individual and developmental differences are shown to be related to differences in task interpretation and understanding, definition of task relevant features and strategies, and the effectiveness and efficiency with which processes are executed. The specific findings as well as the general position are discussed in terms of implications for diagnosis and optimization in instructional settings. (Author/MP)

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Understanding the Development of Analogical Reasoning Ability

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Summary

This paper takes the position that theories about individual differences in childhood and theories about cognitive development would both be enhanced if the two lines of research were integrated. The heuristic value of this position is illustrated in the context of analogical reasoning tasks. A general model of analogy solution and potential sources of variability in performance are outlined. Specifically, for both geometric and verbal analogy solution individual and developmental differences are shown to be related to differences in task interpretation and understanding, definition of task relevant features and strategies, and the effectiveness and efficiency with which processes are executed. The specific findings as well as the general position are discussed in terms of implications for diagnosis and optimization in instructional settings.

A notable characteristic of the research reported in this symposium is the emphasis on performance that is not limited strictly to laboratory situations. Rather, the focus is on tasks that already have some considerable degree of utility and validity out there in the world, such as aptitude and intelligence tests items. Somehow these tests capture reliable and systematic individual differences in cognition. But the knowledge gained from these standardized tests has had very little impact on efforts to understand or optimize learning. To address this problem, researchers are seeking to identify the cognitive bases for individual differences in performance.

Unfortunately, there has been very little integration of research on individual differences with research on cognitive development. This is surprising because standardized tests of intelligence or aptitude are widely administered to children and are sometimes used to make decisions that effect their educational opportunities. But little is known about the relationship between individual differences and developmental change. Consider how high IQ children might differ from low IQ children over the course of development. Some of the possible relationships are outlined in Figure 1. Proficiency on a particular information processing skill, such as mental rotation or retrieval from long-term memory, is plotted as function of age. The graph in the upper-left corner represents the possibility that children who score poorly on a test of mental ability lag behind high-scorers, but they share a single developmental course. This seems to have been the idea that guided Binet in construction of intelligence tests. Figures 1b and 1c are variations on this theme. Figure 1d represents the idea that a skill may show development without differentiating between high- and low-scorers, and 1e illustrates that a skill may consistently distinguish among individuals without undergoing

developmental change. These are just a subset of the possibilities. We would argue that theories about individual differences in childhood and theories about cognitive development would both be enhanced if the two lines of research were integrated.

In an effort to understand individual differences and developmental change, we have focused on how children solve analogical reasoning problems. Both verbal and figural analogies are used widely in tests of intelligence for children and adolescents, and they have a number of properties of interest from a developmental point of view.

Consider the analogy in Figure 2, which has both verbal and geometric forms. Terms A, B, and C constitute the "stem" of the analogy, and the task is to identify a D term that fulfills the analogy. An analogy is correct if A is to B as C is to D. So in this case an appropriate D term would be "ellipse." In most tests students select a D term from several alternatives. In experimental versions, students are often asked to evaluate whether an analogy is true or false, or they may be asked to generate a correct D term. Dependent measures include the speed and accuracy of responding, and in some cases the rationale given for a particular response.

The usual starting point for work on analogy solutions has been a general processing theory first described by Spearman (1923) and recently elaborated by Sternberg (1977). These processes are illustrated in Figure 3. According to this theory, a subject must encode or represent internally the terms of the analogy. To solve the analogy, one must infer the relationship between the A and B terms and subsequently apply or test for that relationship between the C and D terms. Sometimes it is also necessary to identify the relationship between A and C, a process Sternberg calls mapping. Successful solution depends on being able to execute these and other processes accurately, efficiently, and in an appropriate sequence.

Given this framework, there are many possible sources of variability in performance. One such source concerns how people go about solving analogies. For example, do individuals solve these problems by using the set of processes described by Spearman and Sternberg? Do some people omit certain processes in their solution strategies, or do they sequence these processes differently than other people? Questions like these have recently been investigated using reaction time methods (Bisanz, Pellegrino, & Cohen, in preparation; Mulholland, Pellegrino, & Glaser, 1980 ; Sternberg & Rifkin, 1979). It has been shown that these methods are useful in identifying both particular solution strategies and the speeds of specific processes that comprise those strategies. On the basis of one such study, Sternberg and Rifkin (1979) recently concluded that both strategies and speeds of processes may vary as children grow older, depending on the type of analogy problem that is being solved.

Obviously such methods have great promise, but in some ways they barely scratch the surface of the problem. To use reaction time methods effectively, accuracy must be high. Consequently plenty of practice is provided, problems tend to be relatively straightforward and students understand the task perfectly. These conditions rarely exist in the case of standardized testing. When experimental conditions are made more similar to the usual classroom situation, a new set of questions comes to the fore. We will illustrate this by describing research involving "dot analogies" and verbal analogies.

Bisanz and Bisanz administered "dot analogies" like the ones shown in Figure 4. A specially designed set of true-false problems was administered to students in grades 4, 8, and college. Dot analogies are essentially geometric analogies that involve transformations in number. There are several different ways in which a dot analogy can be "solved," but

correctness of the solution may vary. Consider the problems in Figure 4. Most of us would respond, from top to bottom, "true, false, false." The reason is that we infer the A--B relationship to be +2, so we would only respond "true" when C--D is also +2. Our inferred transformation, +2, involves both direction and magnitude. Now consider a student who attends only to direction. Such a person would respond "true" to both 4a and b, because both involve positive A--B and C--D transformations. Likewise, a person who considers only magnitude would respond "true" to problems a and c, but not b. So we can distinguish strategies with a double criterion (magnitude and direction) from those with only a single criterion. Any of these would be task-relevant criteria, but the double criterion is more stringent.

Students were tested in group sessions and were given very standard instructions. Sample analogy problems were described, but none involved dots or transformations of number. In effect, when they began to work on the dot analogies students had to identify the relevant stimulus attributes and establish criteria for true-false decisions all on their own. By observing the pattern of responses across 40 problems we could determine if a student was using a double-criterion strategy, a single-criterion strategy, or a strategy that was either task-irrelevant or too inconsistent to be classified.

At this point only preliminary analyses have been conducted and additional data are being collected, so the following figures and interpretations are to be taken with a grain of salt. After classifying each student, it was found that the proportion of students who use one of the three task-relevant strategies increases dramatically with age. In grade 4, only 5% consistently used a task-relevant strategy, whereas the rest either used an irrelevant strategy or could not be classified. In

grade 8, about 64% used a task relevant strategy, as did 94% of the college students. Furthermore, among the students who used one of these task-relevant strategies, there was an increase with age in the use of the more stringent, double-criterion strategy, from zero in grade 4 to 65% in grade 8 to 91% in college. So fairly strong trends appear in the data. As children grow older they are more likely to spontaneously identify task-relevant attributes of analogy problems, and they are also more likely to invoke a more stringent criterion for judging an analogy to be true. As more data become available, it will be possible to determine if individual differences on this task relate to differences in school achievement and intelligence test scores.

The dot analogy task seems to be sensitive to differences in the way children spontaneously interpret the task, define the relevant features, and construct decision rules. Our second example, verbal analogy solution, also illustrates that when there is substantial variability in getting the correct answer, this variability is related to differences in how the task is understood as well as to the effectiveness and efficiency with which processes are executed.

In one study (Goldman, Parseghian, Pellegrino, & Sallis, in preparation), 8- and 11-year-olds were given 50 analogy items in the typical forced-choice format and were asked to give the reason they picked each answer. The items were drawn from tests typically administered to children in this age range. Three findings are of particular relevance. There was wide variability in forced-choice performance: at each age level, the range of scores was 80 percent to 20 percent or chance responding. Second, children who got higher scores gave reasons that reflected an understanding of the requirement that the A--B and C--D relations must match. In contrast children with low scores rarely gave these types of reasons,

even when they were justifying a correct response. The third finding bears on the issue raised at the outset of this paper--on the issue of the relationship between skill differences and age differences: On the task understanding measure, high scorers in the 8-year-old group performed like the high scorers in the 11-year-old group, not like the low scorers in the 11-year-old group. It would seem then that differences in understanding of the analogy task are not likely to be remediated merely by getting older.

The phrase "differences in task understanding" implies that children may be executing different processes in attempting to solve an analogy. There is also the possibility that even when they execute the same process, the outcome or result of that process differs. In a second study (Goldman et al., in preparation), the outcome of the relational inference process, application processes and response selection processes were examined. We did this by a sequential presentation of the item, which is best understood in the context of an example, shown in Figure 5. Suppose that I present you with the first two terms of an analogy: Cat:Tiger and ask, "How do cat and tiger go together?" You respond, "They're both felines, in the same family." I then show you Cat:Tiger::Dog:? and ask you to fill in an analogically correct response and tell me why it is correct. You respond Wolf and say that Dogs and Wolves are in the same family.

By presenting the pieces of the analogy in this way, I have forced you to execute the relational inference process. The outcome of that process is analogically appropriate and you have demonstrated the application of that relationship in generating a fourth term. In the final phase of the procedure, response selection processes were examined. Suppose I present you with Cat:Tiger::Dog:? and give you five alternatives, e.g., (1) Lion, (2) Wolf, (3) Animal, (4) Bark, and (5) Horse. You select a response and justify it. Suppose you choose Wolf. You have maintained your generated

response in the face of other alternatives. In other words, you have resisted interference from the distractors and maintained an analogically correct response. Another outcome of the response selection process is possible. Suppose that you had not generated a correct response, e.g., you might have said Bark. When I present the alternatives, you recognize that Wolf is the analogically correct response so you choose it. You have used the information in the alternatives to facilitate your performance.

If you had given these responses, you would be a highly skilled analogical reasoner. Both 8- and 11-year-olds who do well on a forced choice test of analogical reasoning infer analogically appropriate A--B relations, apply these relations to generate completion terms, resist interference created by the presence of distractors, and use information in the alternatives to facilitate performance. In contrast, low scorers in both of these age groups are less likely to infer analogically appropriate A--B relations. Furthermore, even when they have inferred an analogically appropriate relation, their generated completion terms are not consistent with the previously stated A--B relation and they are not justified in terms of that relation. Thus, if low scorers are executing an application process at all, it certainly appears to be different from the application process necessary for analogical reasoning: Their solutions do not meet the requirement that A--B and C--D relations match. During response selection, low scorers are more susceptible to interference from distractors and less likely to use the alternatives to facilitate their performance.

Thus, individual differences in correctly solving an analogy item in a forced-choice format are accounted for by both differences in the processes that one is attempting to execute and differences in the outcomes of processes that are executed. Furthermore, differences in these factors,

rather than simply age alone, account for differences in performance.

Our purpose in discussing these examples has been to illustrate a number of points. First, a wide range of methods exists for studying developmental change and individual differences in a complex skill like analogical reasoning. We expect that further research will be enhanced by the development of even more sensitive and revealing techniques. Second, performance on analogy problems needs to be considered in terms of a variety of analyses. It is not sufficient to identify a sequence of specific solution processes. It is important to probe further in order to discover differences in the information and criteria that are used to solve these problems. Third, a number of specific questions have been raised that need resolution. How do the selection, use, and speed of particular component processes vary with individual differences in scholastic aptitude or achievement? How do children spontaneously interpret instructions and establish their own decision criteria? What is the role of factual knowledge in the solution process? Answers to these questions should be useful in constructing more integrated theories of cognitive development and individual differences. We anticipate that such theories will contribute to descriptions of the characteristics of cognitive skill that will make it possible to diagnose an individual's strengths and weaknesses and to focus instruction accordingly. With better theories and more powerful diagnostic procedures, the goal of successfully adapting instruction to individual learners will be one step closer.

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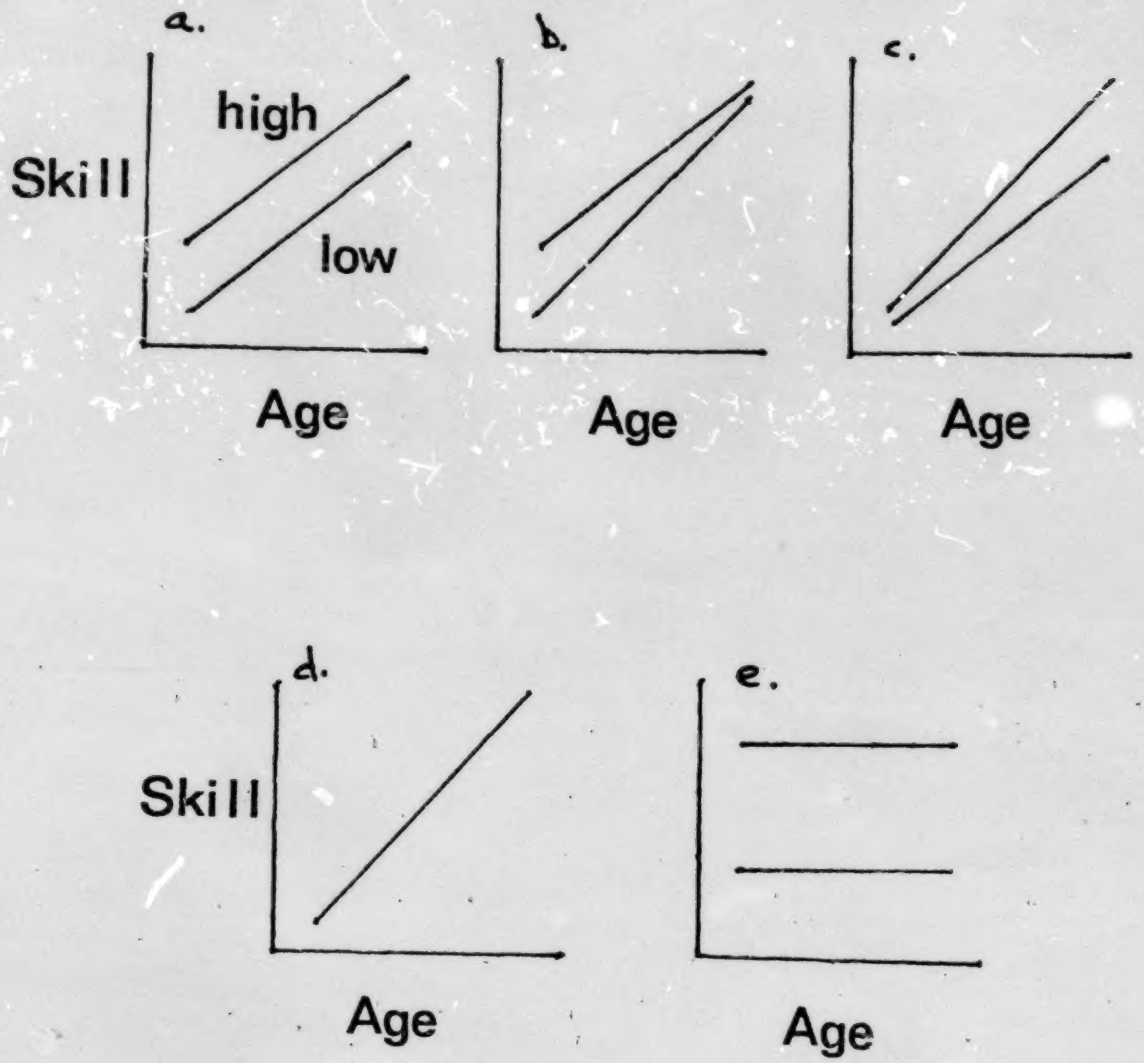

Figure 1
Schematic relationships between individual differences and developmental change.

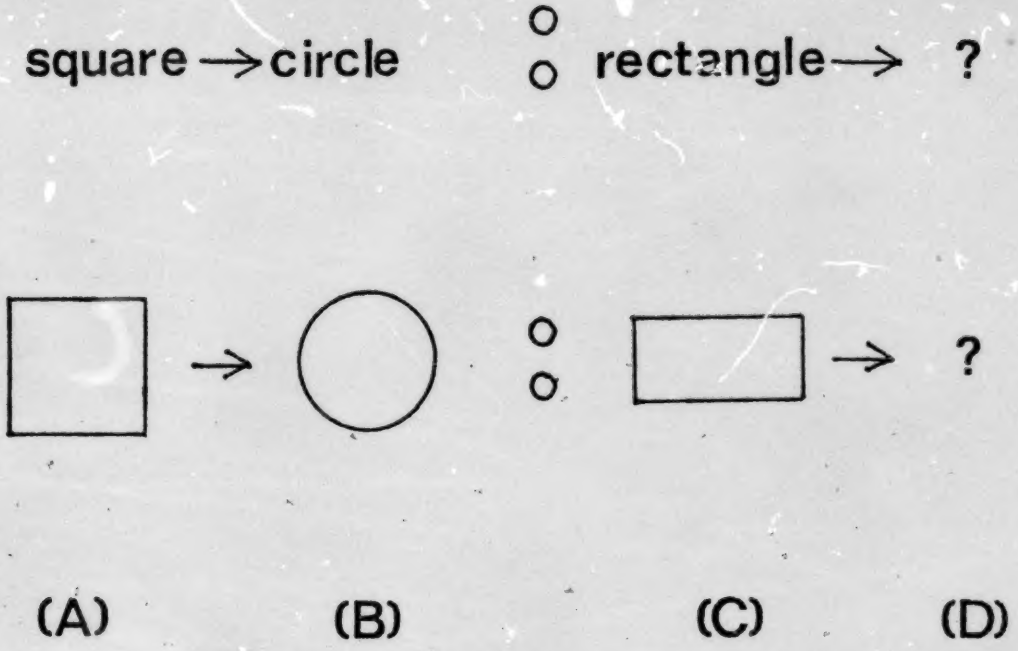

Figure 2
Sample analogy items

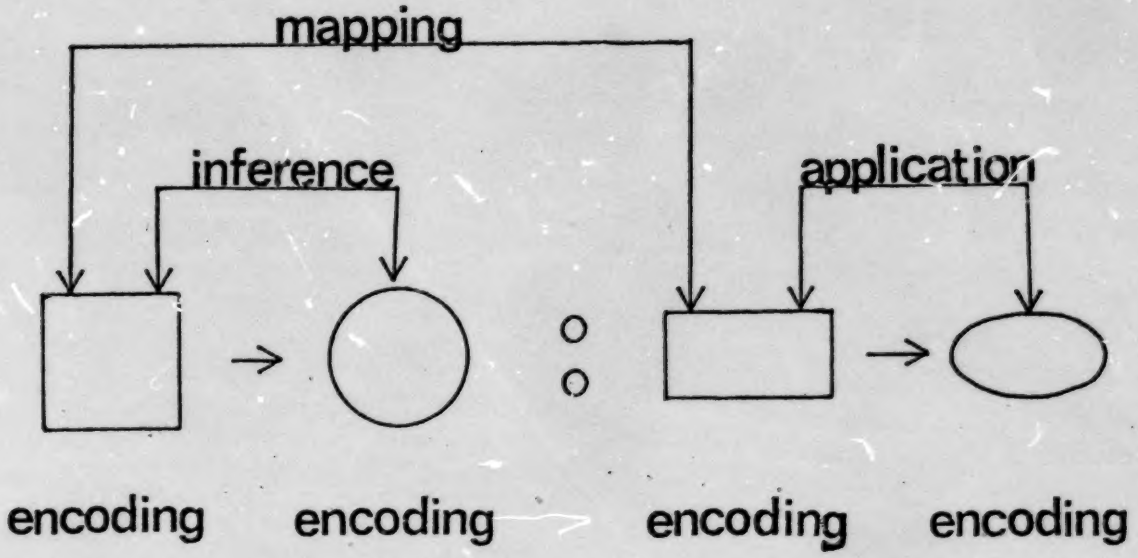

Figure 3.

General Processing Model for Analogy Solution

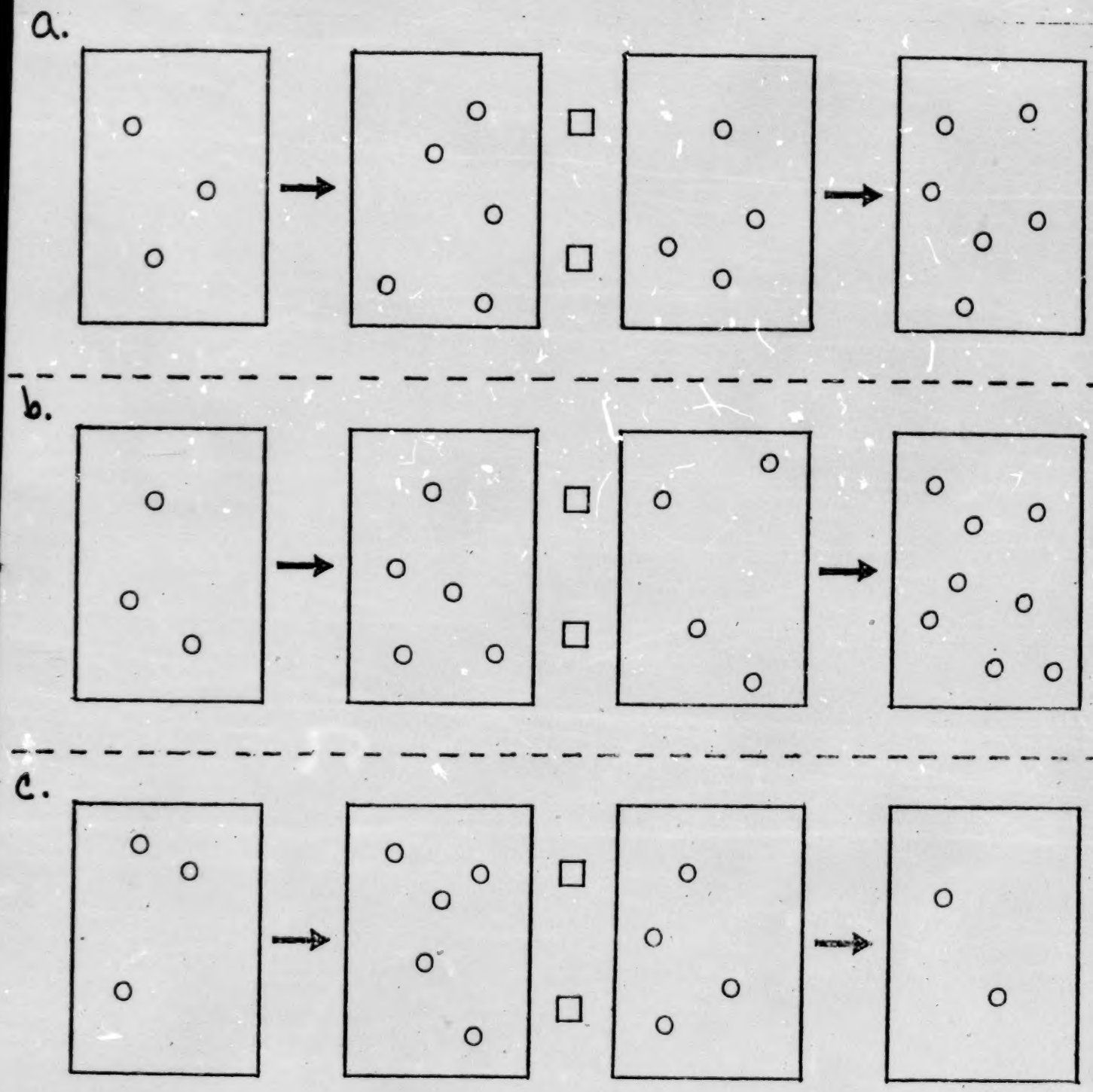

Figure 4 [16]
Dot analogies used by Bisanz & Bisanz

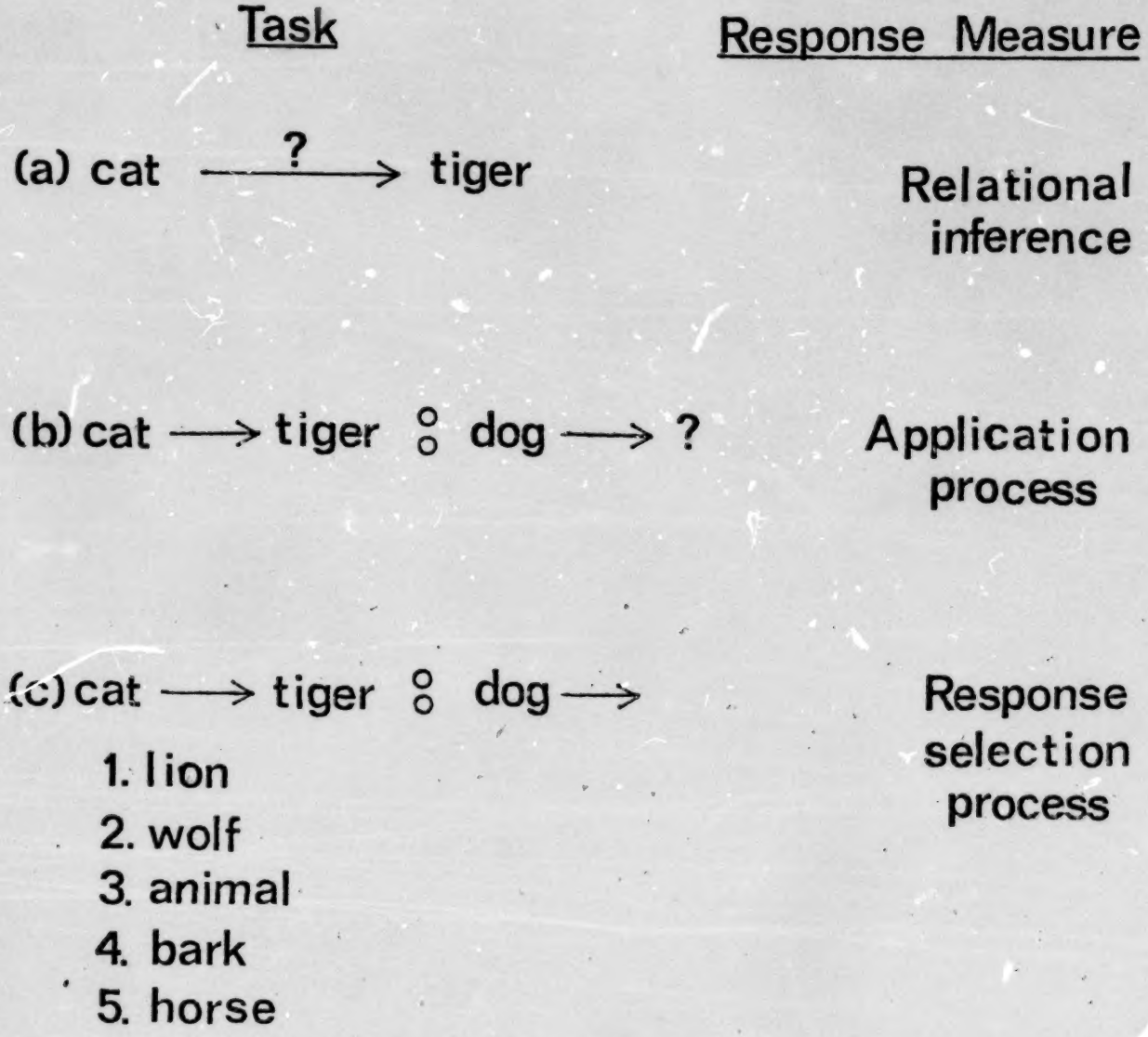

Figure 5

Successive Presentation Method used by Goldman, Parseghian, Pellegrino & Sallis